Savannah River Site
Solid Waste Management Department
Consolidated Incinerator Facility
Operator Training Program

CONSOLIDATED INCINERATOR FACILITY (CIF) COMBUSTION PRINCIPLES (U)

Study Guide

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Revision 02

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FOR TRAINING USE ONLY

REVISION LOG

REV.	AFFECTED SECTION(S)	SUMMARY OF CHANGE
02	All	Formatting changes; revisions to objective levels and material revisions

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REFERENCES

1. Functional Description, *Consolidated Incineration Facility*, Main, Rev. 1

2. WSRC-SA-17, *Consolidated Incineration Facility Safety Analysis Report*, DOE Approval Copy

3. DOE Fundamentals Handbook, *Chemistry, Volumes 1 and 2*, Washington, DC: U.S. Department of Energy, January, 1993, Rev. 0

4. DOE Fundamentals Handbook, *Thermodynamics, Heat Transfer, and Fluid Flow*, Washington, DC: U.S. Department of Energy, June, 1992

5. Westinghouse Savannah River Company Employee Safety Manual 8Q, Item #61, *Personal Protective Equipment*

6. J-SD-H-00002, Functional Description, *Incineration*, Rev. A

7. G-SYD-H-00046, System Design Description, *Incinerator System*, Rev. 0

8. Steven DeCicco, *Combustion Heat and Mass Balances*, 1993 Incineration Conference, Knoxville, Tennessee

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TERMINAL OBJECTIVE

1.00 Given course of instruction and applicable procedures and reference materials, **DEMONSTRATE** understanding of combustion principles through safe and efficient control of the Consolidated Incinerator Facility processes.

ENABLING LEARNING OBJECTIVES

1.01 **LIST** the industrial applications of the combustion process.

1.02 **STATE** the safety precautions associated with the following aspects of the combustion process:

a. Fuels
b. Heat
c. Chemical characteristics

1.03 **DEFINE** the following terms associated with heat transfer fundamentals:

a. Temperature
b. Heat
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d. Sensible heat
e. Latent heat
f. Heat transfer
g. Conduction heat transfer
h. Convection heat transfer
i. Radiant heat transfer

1.04 Given the applicable formulas and variables, **DETERMINE** the following:

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a. Thermal conductivity
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d. Material thickness

1.07 Given the applicable formulas and variables, **DETERMINE** the following factors affecting the rate of convective heat transfer:

a. Convective heat transfer coefficient
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c. Differential temperature

1.08 **DEFINE** combustion.

1.09 **IDENTIFY** the factors necessary for complete combustion.

1.10 **LIST** the chemical constituents of air.

1.11 **IDENTIFY** the by-products of complete combustion.

1.12 **IDENTIFY** the by-products of incomplete combustion.

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1.18 **EXPLAIN** the concerns regarding exothermic reactions in the storage tanks at the Tank Farm to include:

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1.19 **DESCRIBE** the reasons heatup and cooldown rates are controlled and the methods of control.

INTRODUCTION TO THE COMBUSTION PROCESS

Introduction

Combustion is the process of burning. More specifically, it is a rapid chemical reaction that releases energy. An example of a combustion reaction is the burning of coal, where the main reaction involves converting carbon and oxygen to carbon dioxide. A vital process that has been the subject of vigorous scientific research for over a century, combustion accounts for approximately 85% of the world's energy production - and a significant fraction of the world's atmospheric pollution as well.

Combustion is a recognized principle used in many processes. Combustion plays a key role in ground transportation, spacecraft and aircraft propulsion, global environmental heating, materials processing, hazardous waste disposal through incineration, as well as many other areas. Despite this, there is limited understanding of many fundamental combustion processes - how pollutants are formed during these processes, for example.

Combustion is defined in terms of the process variables and applications (boilers, reactors, kilns, incinerators, steam generators, furnaces, etc.) and materials (hydrocarbons, alkanes, organics, wastes, fuels, air, etc.). This course addresses heat transfer, combustion fundamentals and combustion principles.

Purpose

1.01	**LIST** the industrial applications of the combustion process

Combustion is used for controlled and regulated process production. Uses of the combustion process include boilers for heat and steam production, incinerators and kilns for thermal destruction or recombination, distillation and evaporation in industrial processes, and in reactors for energy conversion. Combustion uses fuels and combines them with oxygen in a heated environment. The three elements, heat, fuel and oxygen, comprise the three sides of what is commonly referred to as the fire triangle. Figure 1, *Fire Triangle*, shows the three elements that comprise the fire triangle.

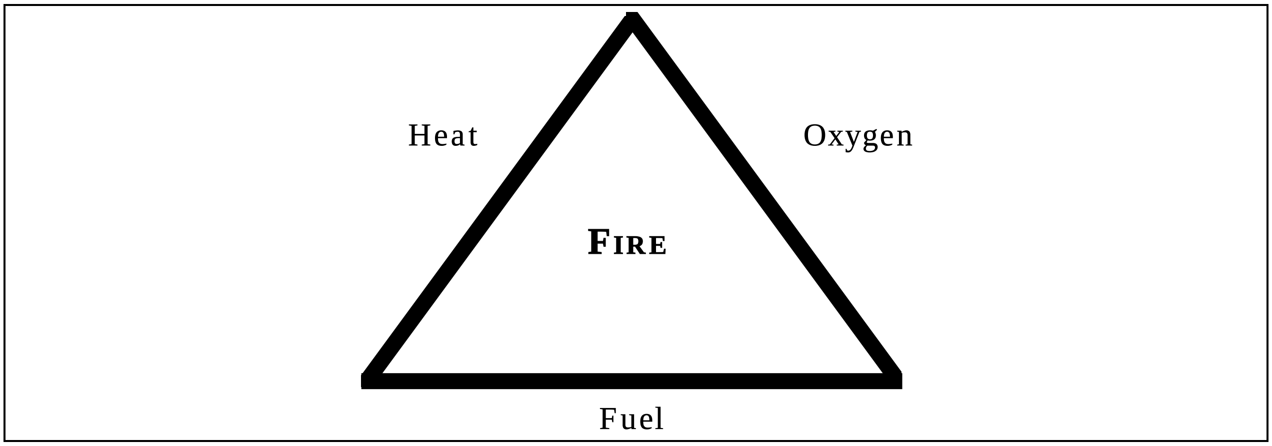


Figure 1, Fire Triangle

In everyday life, we try to avoid combining the three elements to prevent combustion. But, in the incineration process, we combine the three elements in a controlled and regulated environment to thermally destroy or reduce the volumes of waste materials or fuels we inject into the incinerator. Figure 2, *Fire Triangle Comparison to Combustion*, shows the relationship of the elements of both processes.

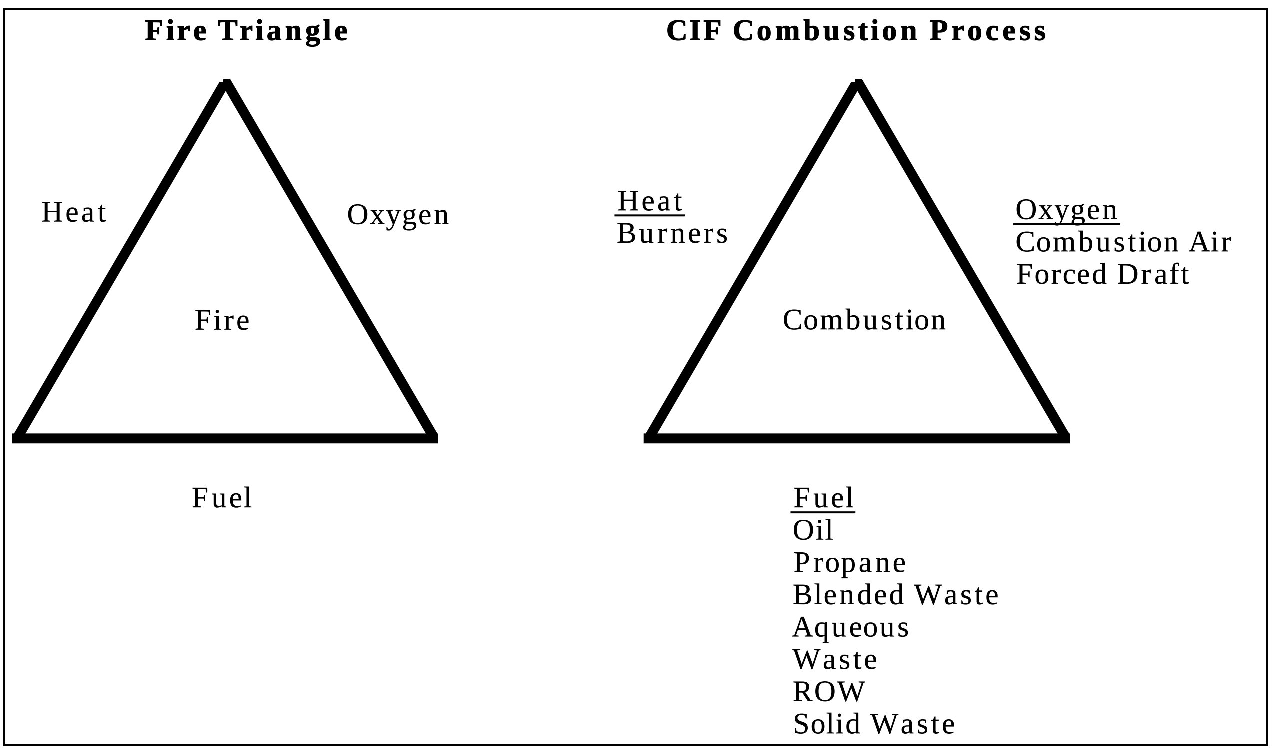


Figure 2, Fire Triangle Comparison to Combustion

Safety

1.02	**STATE** the safety precautions associated with the following aspects of the combustion process: a. Fuels b. Heat c. Chemical characteristics

CIF combustion requires fuels and wastes subjected to heat for the purpose of producing a chemical reaction. Those three aspects alone require operators to be aware of numerous safety aspects.

The nature of the fuels being combusted should be of primary concern. The type of wastes or fuels combusted will determine the required safety concerns. Combusted materials could be classified as waste, hazardous, radioactive, chemicals, petroleum-based, carbon based, organic, etc.. Applicable documentation such as Material Safety Data Sheets (MSDS) which identify flammability, reactivity, health hazards and any other concerns should be made available in a centralized location (as well as having applicable copies in outlying or satellite areas) to all personnel involved with any aspect of the combustion and fuels or waste processes.

Another safety aspect of concern is the heat generated from the combustion process. Surfaces of heat exchangers will be dangerous to touch because of the potential for burns. Associated support and auxiliary systems such as steam, combustion air, fuels, and electrical may also have the potential for heat injuries.

NOTE	Observations have shown that with the CIF RK at an operating temperature of 1400°F, the temperature on the outer surface of the shell will be approximately 320°F.

The final aspect associated with combustion that is a safety concern is the chemical characteristics of a combustion process. Combustion processes are regulated and safeguarded because there is a fine line between controlled combustion and uncontrolled explosion. Combustion conditions are maintained by regulating the amounts of fuels and combustion air supplied to the heat exchanger as well as controlling the pressures, temperatures, and flows for primary and support systems. Operators must exercise vigilance and routinely perform scheduled surveillances and rounds to ensure that all process parameters are kept within defined limits (safety, design, vendor specifications, etc.) and operating criteria.

Review

1) What are four of the industrial applications for the combustion process?

2) Compare the elements of the fire triangle to the elements in the CIF combustion process.

3) Identify three safety concerns associated with the combustion process at the facility.

HEAT TRANSFER FUNDAMENTALS

Introduction

Combustion requires recognizing the various processes occurring in the applicable environment. Consideration of the processes will govern factors affecting facility design, equipment performance, material constituents and process parameters. Heat and mass balance calculations are performed to understand and assist in the design of the complete process from the waste feed injection to the stack. Understanding heat transfer fundamentals is a prerequisite to any discussion of heat and mass balances and the combustion process.

1.03	**DEFINE** the following terms associated with heat transfer fundamentals: a. Temperature b. Heat c. Enthalpy d. Sensible heat e. Latent heat f. Heat transfer g. Conduction heat transfer h. Convection heat transfer i. Radiant heat transfer

Temperature

The temperature (T) of a substance is the measure of the molecular activity of the substance, or a measure of its stored energy. The higher the temperature, the greater the magnitude of the molecular movement within the substance. When a hot body is placed in contact with a cold body, the molecules of the hot body impart motion to the molecules of the cold body and, if the bodies are in contact long enough, the two bodies will be at equal temperature. The energy that flows between the two bodies because of a temperature difference is heat.

Heat

Heat is energy in transit on a molecular level as a result of a temperature difference. The symbol (Q) is used to denote heat transferred. (Q) has units of British Thermal Units (BTU's) which is defined as the amount of heat energy needed to raise the temperature of 1 lbm of water 1 degree Fahrenheit at standard atmospheric pressure. In energy balance equations, heat transferred per unit time is used to indicate heat added or removed from a system with units of BTU/hr. The symbol q is used to indicate the heat added or removed per unit mass. The quantity represented by q is referred to as heat transferred per unit mass and is written :

$$q = Q/m$$

Where:

q = heat transferred per unit mass (Btu/lbm)

Q = heat transferred (Btu)

m = mass (lbm)

Enthalpy

Enthalpy for a combustion system can be generally defined as a measure of the amount of heat contained in a defined amount of a substance at defined standard conditions. Enthalpy is expressed in units of BTU/lb. The amount of heat contained is composed of two types: sensible heat or latent heat.

Sensible Heat

Sensible heat is heat added to or removed from a substance to cause a change in temperature. The units of heat are often defined in terms of how much temperature change they produce. Sensible heat is added to or removed from a substance to the point where a phase change happens. A phase change occurs when a substance changes state from a solid to a liquid, from a liquid to a gas, or vice versa. It takes about 180 BTU's per pound mass to raise the temperature of water from 32°F to 212°F at standard atmospheric pressure

Latent Heat

Latent heat is that amount of heat added to or removed from a substance that causes a change of phase. The most common example is the boiling or vaporization of water into steam or the freezing of water to ice. Both are examples of a change of phase caused by the addition or removal of latent heat. The change of phase of matter requires large amounts of energy. To change water to steam at standard atmospheric pressure requires the addition of 970.3 BTU's per pound mass. To change 1 pound mass of ice to water requires 144 BTU's.

An incinerator system enthalpy profile is shown in Figure 3, *Incineration System Enthalpy*.

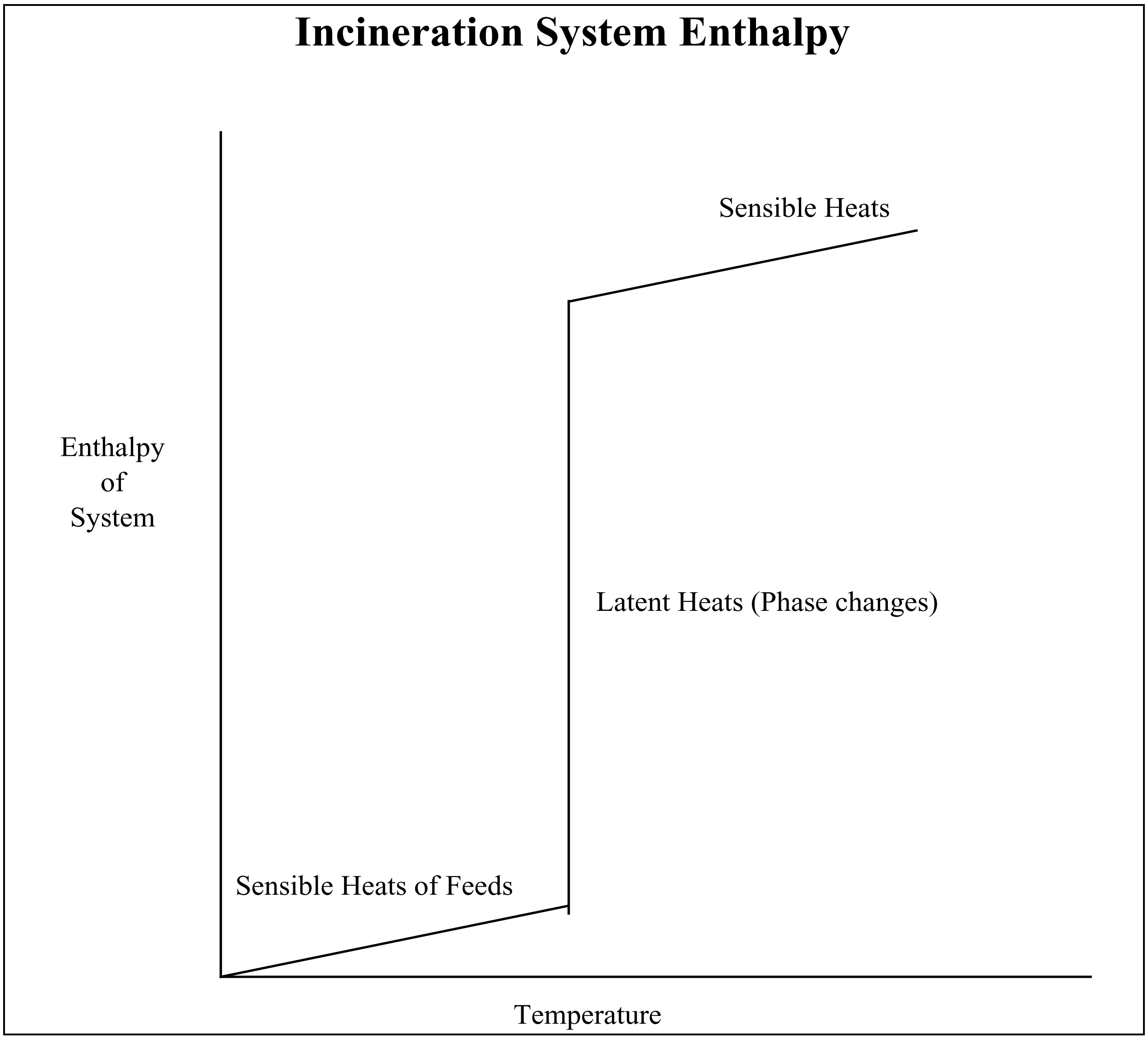


Figure 3, Incineration System Enthalpy

Specific Heat

1.04	Given the applicable formulas and variables, **DETERMINE** the following: a. Specific heat b. Mass c. Differential temperature

Heat capacity (Cp) is the ratio of the heat added to or removed from a substance over the change in temperature produced. Specific heat (cp) is the heat capacity of a substance per unit mass. This is useful in determining how well a fluid will perform in a heat transfer application. This relationship will also tell us how much heat energy we need to raise the temperature of a substance a specified amount.

NOTE	We have defined cp as 1 for water, which we will use as a standard when we compute for the other variables. cp and Q are usually determined empirically (by direct observation) for other materials and, as a result, will be given for most equations.

Example:

How much heat is required to raise the temperature of 3 lbm of water from 40°F to 200°F? (Assume the specific heat of water is constant at 1.0 BTU/lbm-°F)

Solution:

$$cp = Qm\Delta T$$

$$Q = cpm\Delta T$$

$$Q = (1.0 \text{ BTU /lbm-°F}) (3 \text{ lbm}) (200°F - 40°F)$$

$$Q = (1.0 \text{ BTU /lbm-°F}) (3 \text{ lbm}) (160°F)$$

$$Q = 480 \text{ BTUs}$$

1.05 **DESCRIBE** the three methods of heat transfer.

Heat Transfer

Heat transfer is the transfer of energy which occurs as a result of a temperature difference. The understanding of heat flow mechanisms, or heat transfer processes is important since these processes occur continually in the environment. Knowing heat transfer terminology will help relate the study of heat transfer to operation of equipment.

The direction of heat transfer is always from higher temperature to lower. All heat transfer processes fall into one (or a combination) of the following processes. In reality, heat transfer rarely occurs in only one of these processes at a time, but usually involves a combination of processes.

Conduction

Conduction involves the transfer of heat by the process of interactions between adjacent molecules of the material through which the heat is being transferred. Simply put it occurs between objects in physical contact or through the object in the case of a boiler tube wall or in incinerator refractory. The process of conduction can be seen by heating one end of a copper rod. As the molecules in the rod move faster, they share this motion with adjacent molecules in the rod and the temperature rises along the length of the rod. Except for their vibratory motion in the structure of the rod, the molecules have no motion in the rod. This is heat transfer without mass motion and is the mechanism for heat transfer in solids. Figure 4, *Heat Transfer by Conduction*, shows an example of this type of heat transfer.

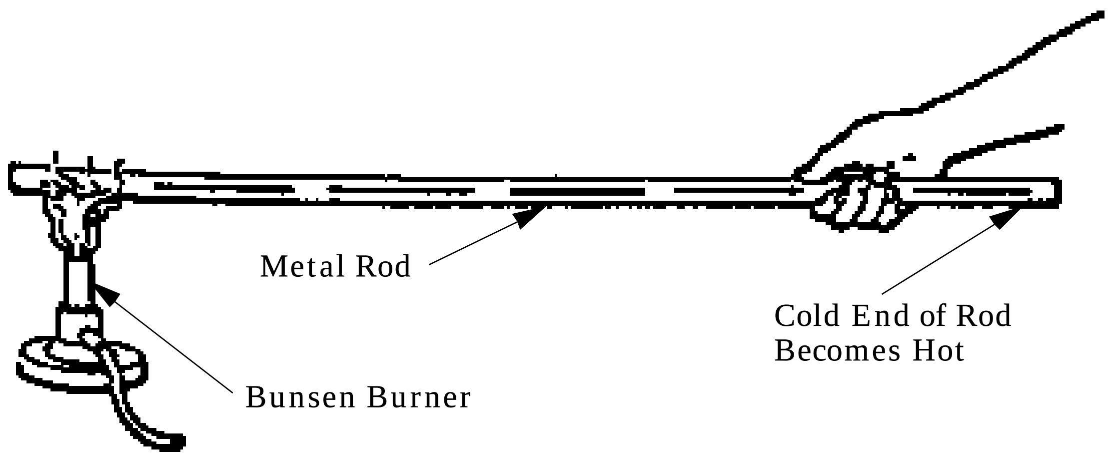


Figure 4, Heat Transfer by Conduction

NOTE	The RK shell is a good example of heat transfer by conduction. Heat is transferred from the refractory on the inner surface, through the insulation to the shell of the vessel.

If the sides of a material are fixed at two different temperatures, heat will continue to flow across it from warmer to cooler. We use this principle in heat transfer devices such as radiators and heat exchangers where a higher temperature fluid gives up heat across a tube wall to a lower temperature fluid. This principle also applies to industrial and private insulation.

Thermal Conductivity

Some materials transfer heat more readily than others. For example, metals conduct heat better than wood. Because of this, a metal rod held in a fire would feel hot sooner than a wooden stick. The heat transfer characteristics of a solid material are measured by a property called the thermal conductivity, represented by k, which is measured in BTU/hr-ft-°F. k is the measure of a substance's ability to transfer heat by conduction. The thermal conductivity for most liquids and solids varies with temperature. For vapors, thermal conductivity depends on the pressure. Metals have a high thermal conductivity whereas materials used for insulation, such as wool or fiberglass, have low thermal conductivity. Table 1, *Thermal Conductivity Values for Various Materials*, list the values of k for some common materials.

Material	Thermal Conductivity "k" (BTU/hr - ft - °F)
Copper	226
Aluminum	131
Iron	39
Concrete	0.4 - 0.8
Water	0.3 - 0.4
Saturated Steam	0.0301
Rock Wool	0.03
Air	0.0145

Table 1, Thermal Conductivity Values for Various Materials

1.06	Given the applicable formulas and variables, **DETERMINE** the following factors affecting the rate of conductive heat transfer: a. Thermal conductivity b. Heat transfer Area c. Differential temperature d. Material thickness

The following formula shows how changes in thermal conductivity, surface area, temperature, and material thickness affect the rate of heat transfer by conduction.

$$Q = \frac{k\,A\,\Delta T}{\Delta x}$$

Where:

Q = rate of heat transfer in BTU/hr

k = thermal conductivity of the material in BTU/hr ft °F

A = area available for heat transfer in ft^2

ΔT = temperature difference in °F

Δx = material thickness in ft

The variables in the equation and their relationships to the heat transfer rate are as follows:

- Thermal conductivity is a derived value for various materials. The heat transfer rate is directly proportional to the thermal conductivity of an object.

$$Q \rightarrow k$$

- The surface area available for heat transfer is also important. It is easier to transfer heat through a large surface area than it is through a smaller area. Therefore, the rate of heat transfer is directly proportional to the area available for heat transfer.

$$Q \rightarrow A$$

- Heat transfer by conduction depends upon the temperature difference to provide the driving force. The larger the temperature difference, the faster heat transfer will occur. Therefore, the rate of heat transfer is directly proportional to the temperature difference.

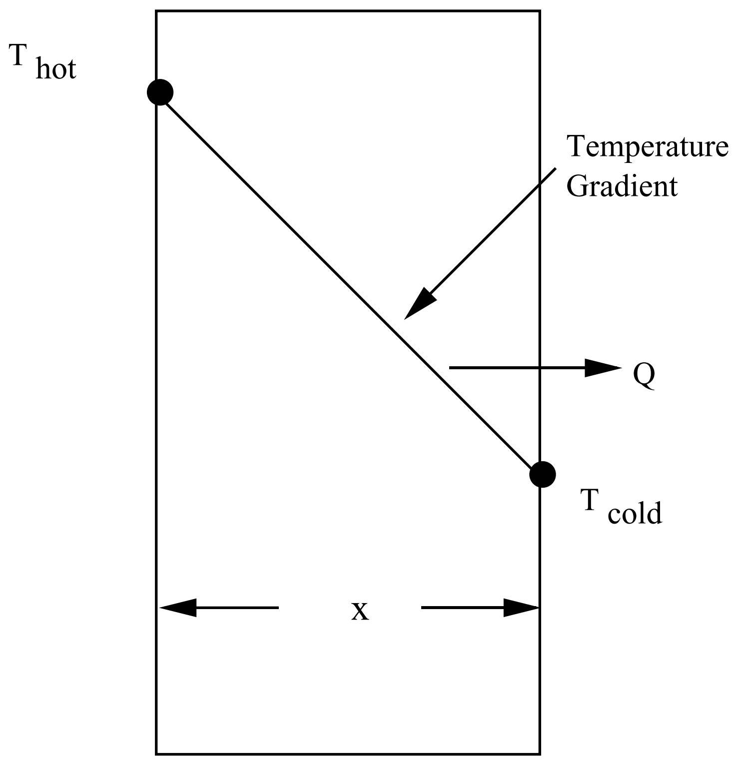
$$Q \rightarrow \Delta T$$

- A thick material will offer more resistance to heat transfer than a thin piece of the same material. Therefore, the rate of heat transfer is inversely proportional to the thickness of the material.

$$Q \rightarrow 1/\Delta x$$

Figure 5, *Thermal Conductivity Through a Material*, shows an application and the factors used to calculate heat transfer by conduction.

Thermal Conductivity Through a Material



$$Q = \frac{kA\ \ T}{x}$$ where

Q = Rate of heat transfer in BTU/hr
k = Thermal conductivity of material in BTU/ft. hr °F
A = area available for heat transfer in ft^2
T = temperature difference in °F
x = thickness of material in ft

The temperature gradient can be represented by $\frac{\ \ T}{x}$

Figure 5, Thermal Conductivity Through a Material

If we consider the variables k and Δx from the equation, we can define the overall conductance of the material as the following:

$$U = \frac{k}{\Delta x}$$

Where U equals the overall conductance of the material in units of BTU/ ft^2 hr °F.

If U is substituted for the other variables, the equation for overall heat transfer becomes the following:

$$Q = U\ A\ \Delta T$$

Convection

Convection involves the transfer of heat by the motion and mixing of macroscopic (large) portions of a fluid (that is, the flow of a fluid past a solid boundary). The thermal energy contained in the molecules of a fluid can be transferred by the fluid to other places. This allows for large amounts of energy to be transported long distances with little energy loss. A common example of convective heat transfer is blowing on a spoon containing hot soup.

The term natural convection is used if this motion and mixing is caused by density variations resulting from temperature differences within the fluid. The term forced convection is used if this motion and mixing is caused by an outside force, such as a pump or fan. The transfer of heat from a hot water radiator to a room is an example of heat transfer by natural convection. The transfer of heat from the surface of a heat exchanger to the bulk of a fluid being pumped through the heat exchanger is an example of forced convection. Figure 6, *Heat Transfer by Convection*, gives an example of this type of heat transfer.

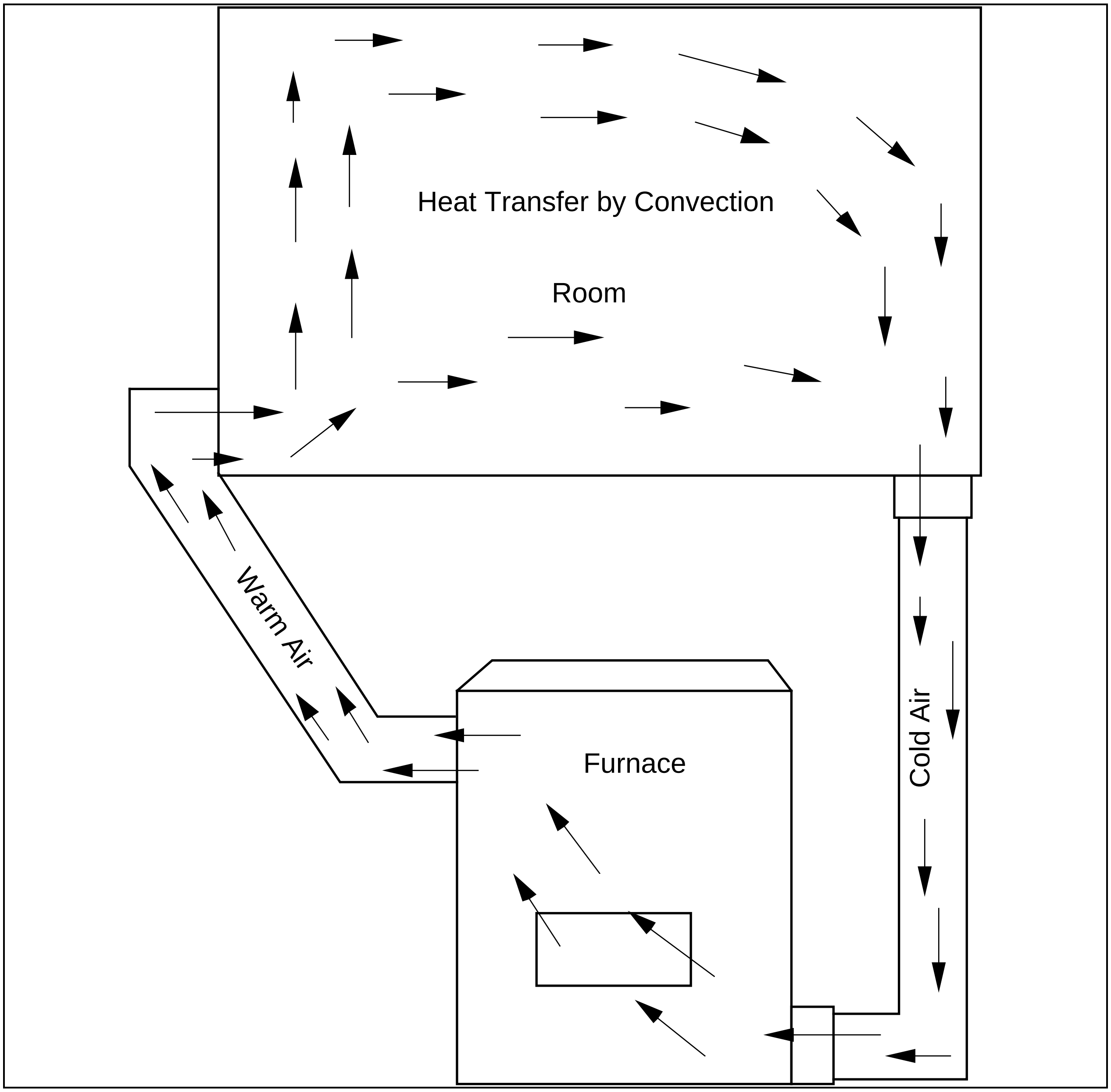


Figure 6, Heat Transfer by Convection

1.07	Given the applicable formulas and variables, **DETERMINE** the following factors affecting the rate of convective heat transfer: a. Convective heat transfer coefficient b. Heat transfer area c. Differential temperature

Heat transfer by convection is more difficult to analyze than conduction because no single property of the medium, such as thermal conductivity, can be defined to describe the mechanism. Heat transfer by convection varies from situation to situation (dependent upon the fluid flow conditions), and it is frequently coupled with the mode of fluid flow.

Convective heat transfer is dependent upon four variables:

- The temperature of the surface of the material
- The temperature of the fluid moving past the surface of the material
- The ability of the fluid layer next to the surface of the material to transfer heat
- The surface area available for heat transfer

These four variables are represented in the following equation:

$$Q = h\ A\ \Delta T$$

Where:

Q = rate of heat transfer in BTU/hr

h = convective heat transfer coefficient in BTU/hr ft^2 °F

A = cross-sectional area for heat transfer in ft^2

ΔT = temperature difference between the material surface and bulk temperature of the fluid flowing past the surface of the material in °F

Convective Heat Transfer Coefficient

The convective heat transfer coefficient, h, defines, in part, the heat transfer due to convection. This coefficient is sometimes referred to as the film coefficient and is representative of a relatively stagnant layer of fluid between the heat transfer surface and the bulk of the flowing fluid. Common units used to measure the convective heat transfer coefficient are BTU/hr-ft^2-°F. Highly polished surfaces and materials such as Teflon have relatively low values of h. Rough or abrasive surfaces have higher values of h. Fluid properties also have a large effect on h. Heat transfers involving a phase change (boiling or condensing) have higher values of h than single phase convection heat transfer. Less viscous liquids like water have higher values of h than more viscous liquids such as oil. The range of values for h reflect the possible variations in surfaces, phases and fluids. Table 2, *Convective Heat Transfer Coefficients*, shows some representative values of h for various phase related processes.

Phase Related Processes	Convective Heat Transfer Coefficient (h) BTU/ hr ft^2 °F
Condensing Steam	1,000 - 20,000
Boiling Water	300 - 9,000
Heating or Cooling Water	50 - 3,000
Superheating Steam	5 - 20

Table 2, Convective Heat Transfer Coefficients

Notice that the ranges of the values for h are large. This is due to the wide variation in the fluid to-surface interfaces.

In practice, analysis of heat transfer by convection is determined empirically. Convection heat transfer is treated empirically because of the factors that affect the stagnant film thickness. Some of these factors are:

- Fluid velocity
- Fluid viscosity
- Heat flux
- Surface roughness

Convective heat transfer occurs between the layer of fluid in contact with the material surface (referred to as the laminar layer; a smooth layer of fluid between material and the bulk of the fluid) and the bulk of the fluid flowing past the surface. The laminar layer touches the surface so heat is transferred by conduction. After heat transfers through the laminar layer, it enters the bulk of the fluid where turbulent mixing of the macroscopic molecules occurs. Because of fluid flow turbulence, the laminar layer is relatively thin. This produces a large temperature gradient and the rate of heat transfer is high. Figure 7, *Convection Heat Transfer Through a Fluid*, shows an application of convective heat transfer from a heated surface to a fluid in turbulent flow.

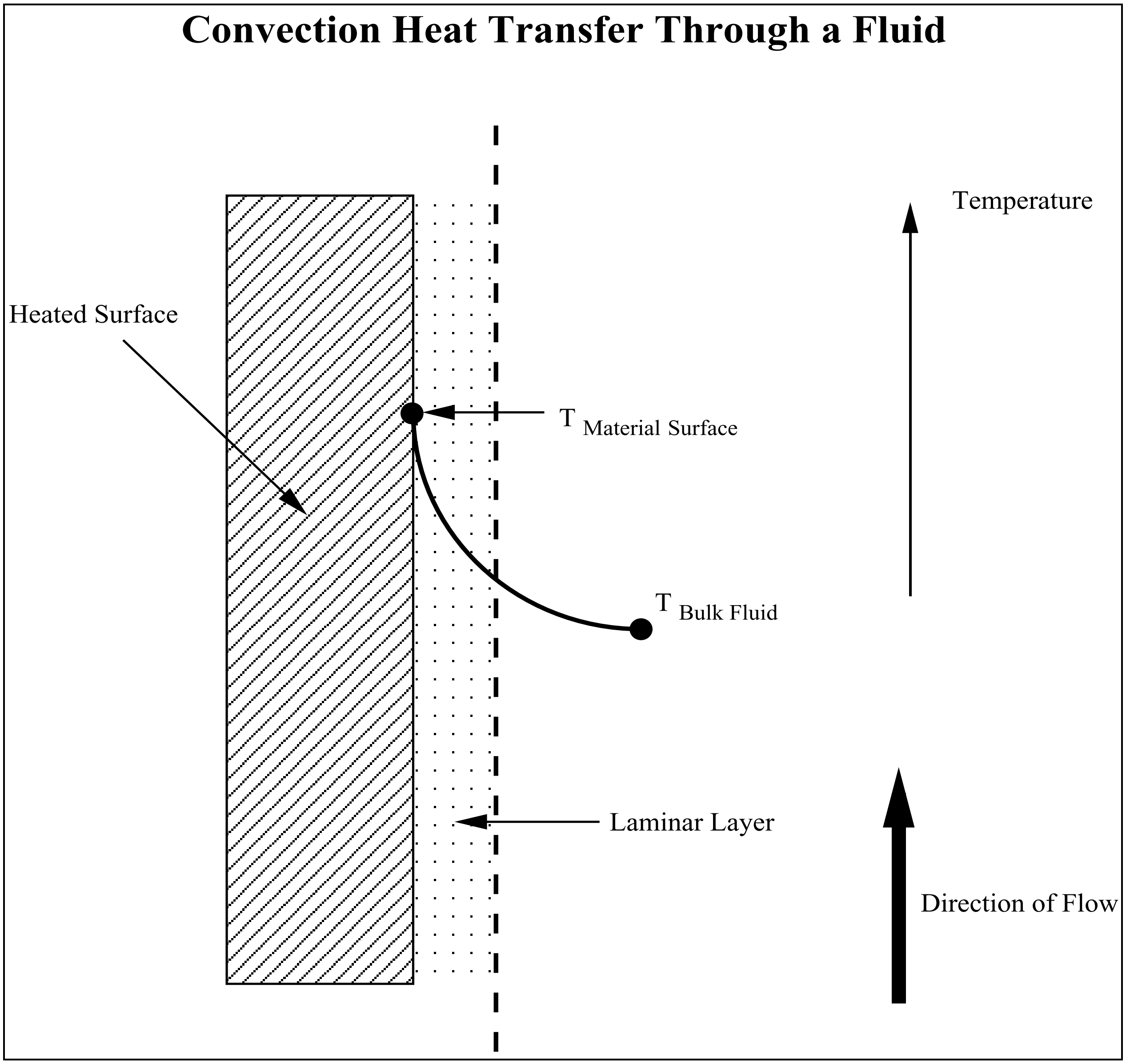


Figure 7, Convection Heat Transfer Through a Fluid

NOTE Analysis of the convection heat transfer occurring in the RK would show that the temperatures at the discharge side of the shell are different than the temperatures at the feed end. Consider the difference in the velocity and viscosity of combustion gases and particulate matter and the temperature difference due to the surface roughness of the vessel.

Radiant Heat Transfer

Thermal radiation occurs between any two objects at different temperatures. Any object or fluid with a temperature above absolute zero emits or gives off radiant energy. The amount of energy emitted is proportional to the absolute temperature of the object. Radiant heat transfer involves the transfer of heat by electromagnetic radiation that is due to the temperature of a body. Most energy of this type is in the infra-red region of the electromagnetic spectrum although some of it is in the visible region. The term thermal radiation is frequently used to distinguish this form of electromagnetic radiation from other forms, such as radio waves, x-rays, or gamma rays. The transfer of heat from a fireplace across a room in the line of sight is an example of radiant heat. Figure 8, *Heat Transfer by Radiation*, gives an example of this type of heat transfer.

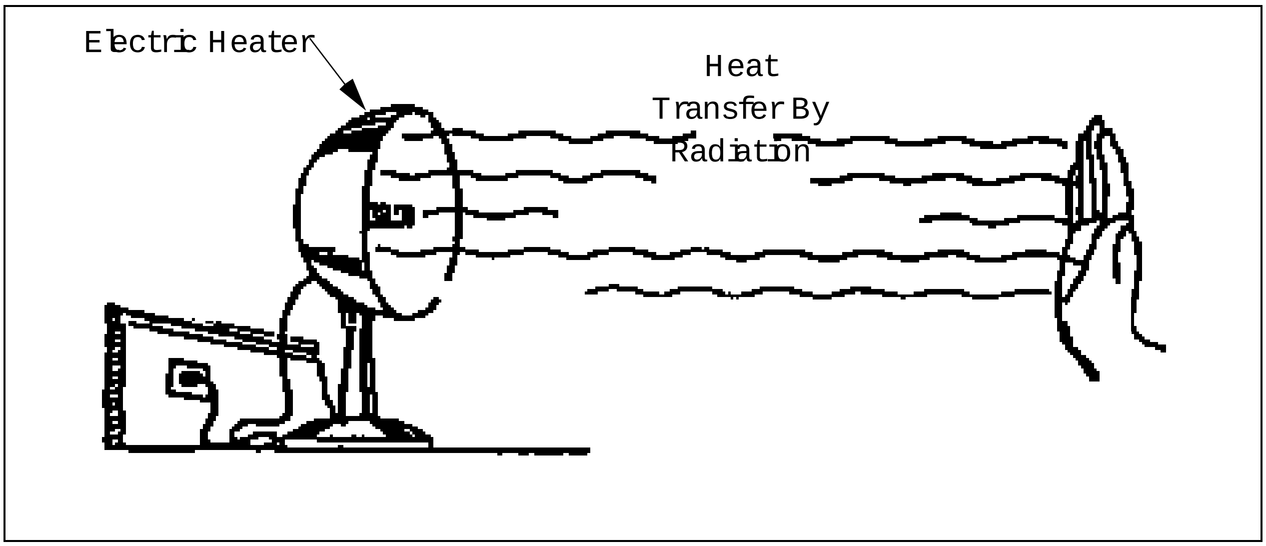


Figure 8, Heat Transfer by Radiation

Radiation heat transfer does not need a medium such, as air or metal, to take place. Any material that has a temperature above absolute zero gives off some radiant energy. When a cloud covers the sun, both its heat and light diminish. This is a familiar example of the effect of heat transfer by radiation.

The First and Second Laws of Thermodynamics

The first law of thermodynamics is referred to as the Conservation of Energy principle, meaning that energy can neither be created nor destroyed, but rather transformed into various forms as the fluid within a control volume is being studied. This law of thermodynamics states that energy can only be altered in form. Energy in thermodynamic systems is composed of kinetic energy (KE), potential energy (PE), internal energy (U), and flow energy (Pv); as well as heat and work processes. For any system, energy transfer is associated with mass and energy crossing the control boundary, external work and/or heat crossing the boundary, and the change of energy stored in the control volume. The first law can be demonstrated by the use of heat and mass balance equations.

The Second Law of Thermodynamics was needed because the first law does not define the energy conversion process completely. The first law is used to relate and to evaluate the various energies involved in a process. However, no information about the direction of the process can be obtained by the application of the first law. Early in the development of thermodynamic principles and theories, investigators noted that while work could be converted completely into heat, the opposite was never true for a cyclic process. Certain natural processes were also observed to always occur in a certain direction (e.g. heat transfer always occurs from a hot to a cold body). The second law was developed to explain these natural occurrences.

Heat and Mass Balance Equations

Heat and mass balance equations account for the chemical properties of the waste streams, system boundaries, operational modes, control operation, operating parameters, and emissions. Heat and mass balance equations provide information regarding waste feed rates, heat release rates, gas flows, operating temperatures and pressures, air flows, gas concentrations, equipment sizing, etc..

Each waste or fuel stream that enters, leaves, or accumulates in the system and contains mass and heat must be accounted for in the equations. Detailed heat and mass balance equations must account all streams to allow for proper design and specification of combustion equipment. Some of the streams that require consideration are as follows:

Inputs

- Waste streams - mass, both inert and combustible, sensible heat, heat of combustion, and requirement to overcome latent heat of vaporization if they are liquids
- Combustion and in-leakage (or infiltration) air - mass from oxygen, nitrogen, and moisture, sensible heat and latent heat of vaporized moisture
- Fuels - mass, both combustible and ash, sensible heat, heat of combustion, and requirement to overcome latent heat of vaporization if they are liquids
- Water - mass, sensible heat, and requirement to overcome latent heat of vaporization
- Reagents (Caustic) - mass, sensible heat, heat of reaction
- Heat of compression (from fans) - sensible heat only

Outputs

- Combustion gases - moisture and fly ash Z(removes mass, sensible heat and latent heat of water vapor
- Ash - removes mass and sensible heat
- Scrubber effluent/purge - removes mass of water, dissolved and suspended solids, sensible heat
- Cooling chamber - removes sensible and latent heat
- Heat losses - sensible heat only

Combustion systems must also account for accumulation in the equations. Accumulation is energy that remains in the system without additional input from fuels or wastes. Some of the sources of accumulation are refractories, slag or ash on the kiln walls, or salts and ash in the scrubber.

Figures 9 and 10, *Mass Balance Equation*, and *Energy Balance Equation*, respectively, show graphical representations of the factors used in the equations.

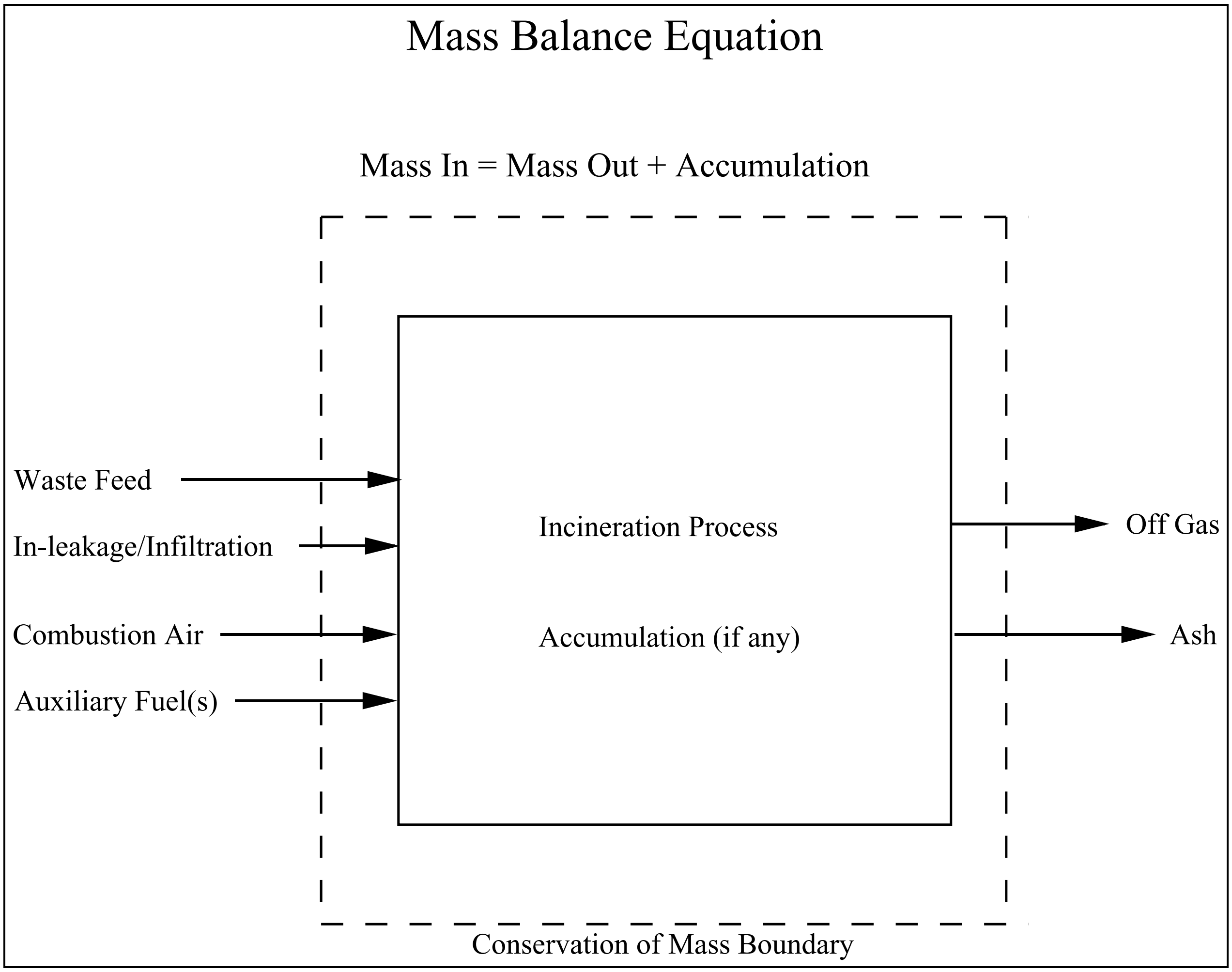


Figure 9, Mass Balance Equation

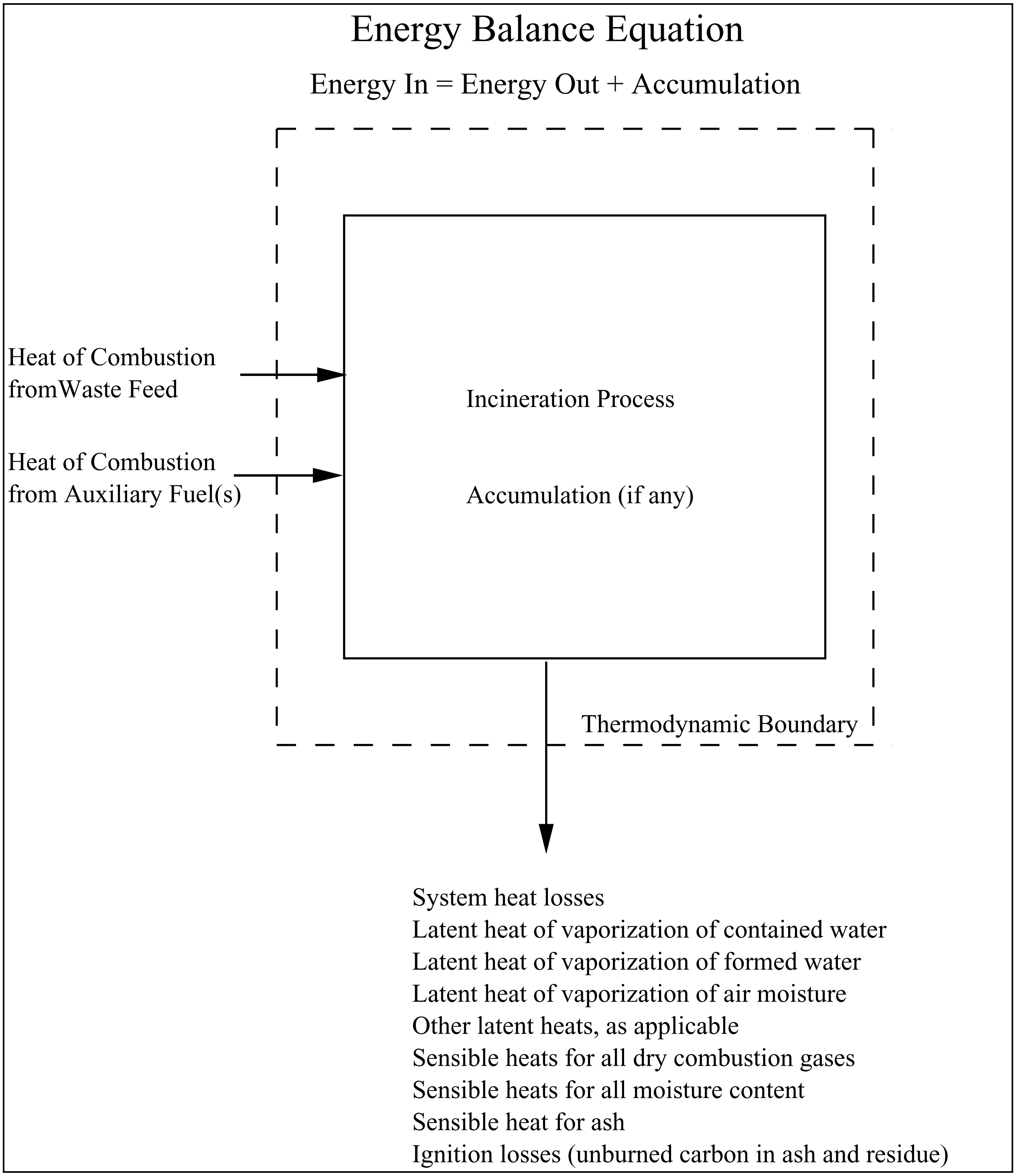


Figure 10, Energy Balance Equation

Heat and mass balance equations largely ignore the effect of heat transfer; that is, the equations assume heat transfer is perfect and complete. As an example, if a combustion process was used to decontaminate a sludge that was slightly contaminated (<1% organics) the major source of heat would be the auxiliary fuel. The heat and mass transfer balance equation would take the input and divide it among the following terms:

- Moisture evaporation in the sludge - sensible heat to raise the water temperature to boiling, latent heat to change it to vapor, and sensible heat to raise the vapor temperature
- Raise temperature of organic sludge by increasing it’s enthalpy; sensible heat using heat capacity of the sludge
- Raise temperature of combustion gas and excess air by increasing enthalpy; sensible heat using heat capacities of gaseous components; latent heat of vaporization of the moisture

No where in the calculation is the efficiency of the heat transfer included. In practice, the heat transfer mechanisms to be considered include:

- Radiant heat transfer from the auxiliary fuels to the sludge, gases, and refractory walls
- Radiant heat transfer from the walls to the gas and conductive heat transfer from the walls to the sludge
- Convection heat transfer from the gases to the sludge

Because the heat transfers are not perfectly efficient, the actual combustion gas temperature will be higher and the sludge temperature will be lower than the values attained from heat and mass transfer equations. In other words, less of the heat is transferred from the burners to the sludge.

Review

1) What are the three terms identified by the symbols in the equation q = Qm?

2) Define specific heat and explain why, when solving heat transfer equations, we assume the value of specific heat to be equal to 1.

3) How much heat is required to raise an object with 10 lbm from 150°F to 375°F?

4) Applying 250 BTUs to an object with 10 lbm will cause how much of a change in temperature?

5) Applying 100 BTUs will cause a change of 300°F to an object with how much mass?

6) Identify the three types of heat transfer and give a CIF example of each.

7) Which heat transfer coefficient is representative of a stagnant layer of fluid between the heat transfer surface and the fluid medium? What are three of the four factors that affect the film thickness?

8) Using the equation below, answer the following question associated with heat transfer by conduction.

$$Q = \frac{k\ A\ \Delta T}{\Delta x}$$

a. What is the required heat transfer rate to raise the temperature of a copper plate five inches thick with a surface area of 25 ft^2 from 85°F to 150°F?

b. Applying 2500 BTU/hr will cause how much change in temperature on the same copper plate?

c. Applying 2500 BTU/hr to an aluminum plate with the same dimensions would cause how much change in temperature?

9. Answer the following questions for the convective heat transfer coefficient using the equation given below:

$$Q = h\ A\ \Delta T$$

   a. What is the convective heat transfer coefficient if 25,000 BTU/hr were transferred by a 50°F change in temperature across a surface area of 25 ft^2?

   b. What phase related process might this be associated with?

10. What are four factors that effect the convective heat transfer coefficient?

COMBUSTION PRINCIPLES

Introduction

1.08	**DEFINE** combustion

Combustion may be defined as the chemical union of the combustible part of a fuel and the oxygen of the air, controlled at such a rate as to produce useful heat energy. The principle combustible constituents in fuels are carbon, hydrogen and their compounds. In the combustion process, the compounds and elements are burned to produce carbon dioxide (CO_2) and water.

Combustion Basics

1.09	**IDENTIFY** the factors necessary for complete combustion.

Combustion takes place when fuel and air are mixed in suitable ratios at high enough temperatures for ignition. Fuels are divided into three categories: solid, liquid and gas. Examples of solid fuels include filter paper, plexiglass, wood, and coal. Liquid fuels include materials like kerosene and gasoline. Materials such as propane and hydrogen are gaseous fuels. Air, which contains gaseous oxygen as one of its components, is a common oxygen source (an oxidizer). Oxidizers can be solid (ammonium perchlorate, used in the space shuttle booster rockets), liquid (hydrogen peroxide), or gaseous (oxygen). An electrical spark is an example of an ignition stimulus or source. In an ideal situation, the combustion process would occur with the exact proportions of air and fuel. In practice, combustion processes occur with varying proportions of fuel and air.

Fuel and Waste Characteristics

Most naturally occurring waste materials and many man-made synthetic products consist primarily of three major chemical elements in one form or another: Carbon (C), Hydrogen (H) and Oxygen (O). Fuel is mostly organic matter that contains large amounts of carbon and hydrogen. Fuel, when combined in correct proportions with oxygen and an ignition source, produces heat. Commonly used fuels include oils, benzene, paper, rags, plastic, rubber, etc..

There are many minor components of fuels and wastes that produce unwanted pollutants when combusted. Some of these are: organic forms of Nitrogen (N), organic forms of Sulfur (S), organic forms of Chlorine (Cl), organic halogens and phosphorus, and alkaline metals (Sodium, Potassium and Calcium). Various structures of the elements and compounds and their chemical contents effect many parameters of the waste materials including combustibility, heat release rate, volatility and toxicity. Small quantities of sulfur are present in most fuels. Although sulfur is combustible and contributes slightly to the heating value of the fuel, its presence is generally harmful because of the corrosive nature of its compounds. These elements are an important consideration from the standpoint of air pollution and emissions control.

Waste materials also contain some inorganic elements in small or trace quantities. Commonly, these elements contain the "heavy metals" which can be either carcinogenic (those having the ability to cause cancer such as Arsenic, Beryllium, Cadmium, and Chromium) or non-carcinogenic (Antimony, Barium, Lead, Mercury, Selenium, Silver and Thallium).

Fuel oil and other combustible liquids may be pressurized and sprayed through tiny nozzles to produce a fine mist which increases the surface area. This spraying process is referred to as atomization. Atomization allows the fuel to efficiently burn and produce the gases needed for combustion. Atomization is achieved by mixing pressurized liquids with pressurized steam or air in the mixing chamber of the burner before passing through the tiny nozzles in the tip of the burner gun. Some liquids are so thick that they must first be heated in order to be sprayed. Most gaseous fuels do not need to be pre-heated for ignition. However, these gases, like the other fuels, must be evenly mixed with air to achieve efficient combustion.

Solid fuels such as paper and rags contain significant moisture. The moisture content of these solids affects ignition and combustion performance. The incinerator, when at operating temperature, will also evaporate a mixed aqueous waste which is mostly water.

The major components of fuels are important to consider when performing heat and mass balance equations. Virtually all of the heat produced and much of the combustion gases produced during incineration comes from oxidizing carbon and hydrogen with air. The main aspect for consideration when accounting for the minor components is the control of emissions to the atmosphere.

Combustion Air

1.10	**LIST** the chemical constituents of air.

Air, the usual source of oxygen for combustion in most applications, is a mixture of oxygen, nitrogen, and small amounts of water vapor, CO2, argon, and other elements. The chemical composition of dry air is shown in Table 3, *Composition of Combustion Air*.

Chemical	Volume (%)
Nitrogen	78.09
Oxygen	20.95
Argon	0.93
CO_2	0.03
Neon, helium, krypton, hydrogen, xenon, ozone, radon	<0.003

Table 3, Composition of Combustion Air

The amount of combustion air has three classifications: stoichiometric (ideal or theoretical), starved, and excess air. Maximum combustion temperatures are always at the stoichiometric value or condition. If the amount of combustion air is greater or less than the stoichiometric values, the combustion temperature is lowered.

If waste destruction will be carried out in a multi-step process, a starved air environment may be used. The first stage may be operated at less than ideal conditions if the latter stage(s) are supplied enough air to ensure complete combustion. Sometimes the starved air is used to initiate further reactions in the latter stages of combustion to produce chemical structures that absorb some of the heat from the combustion byproducts.

Due to inadequate mixing or other non-ideal conditions in the combustion process, more oxygen (or combustion air) is supplied than is theoretically required. This is referred to as excess air. The excess air ensures that each carbon and hydrogen molecule or other combustible element are oxidized to the final combustion product. The amount of excess air will vary depending upon desired operating temperatures, chemical characteristics of the wastes and fuels, and the specific incineration design.

The amount of excess air will vary with the temperature, fuel characteristics, pressures required in the combustion vessel, and the type of firing equipment. For instance, as the heating value of the CIF Fuel Oil and Blended Liquid Waste varies from individual shipments, operators will need to adjust excess air accordingly. The adjustments required for fuel oil with varying heat release rates can be seen in Table 4, *RK Fuel Oil Varying Excess Air Requirements*.

RK Fuel Oil

Heat Release Rates - a) 7.5 x 10^6 BTU/Hr; b) 6.75 x 10^6 BTU/Hr

High Heating Value - 19,200 BTU/lb

Fuel Composition (%)

Carbon (C) - 87.01

Hydrogen (H) - 12.79

Nitrogen (N) - 0.05

Oxygen (O) - 0.15

Excess Air (vol%)	**Oil Flow (Pounds/Hr)**	**Air Flow (Pounds/Hr)**	**Air / Fuel Mass Ratio**
0	390.631 / 351.56	7476.1 / 6728.5	19.1
10	390.631 / 351.56	8223.71 / 7401.3	21.1
15	390.631 / 351.56	8597.51 / 7737.8	22.0
20	390.631 / 351.56	8971.31 / 8074.2	23.0
25	390.631 / 351.56	9345.11 / 8410.6	23.9
30	390.631 / 351.56	9718.91 / 8747.0	24.9
35	390.631 / 351.56	10092.71 / 9083.5	25.8
40	390.631 / 351.56	10466.51 / 9419.9	26.8
45	390.631 / 351.56	10840.31 / 9756.3	27.8
50	390.631 / 351.56	11214.21 / 10092.7	28.7

Table 4, RK Fuel Oil Varying Excess Air Requirements

Table 5, *RK Waste Varying Excess Air Requirements*, shows how the variances in both heat release rates and waste composition affect the excess air requirements.

RK Waste

Heat Release Rates - a) 6.91 x 10^6 BTU/Hr; b) 6.22 x 10^6 BTU/Hr

High Heating Value - 17,951 BTU/lb   Fuel Compositions (%)

(C) a) 79.4 / b) 75.4

(H) a) 16.5 / b) 16.5

(O) a)   4.1 / b)   8.1

Excess Air (vol%)	Oil Flow (Pounds/Hr)	Air Flow (Pounds/Hr)	Air / Fuel Mass Ratio
0	384.94	5612.6 / 5368.6	14.6 / 13.9
10	384.94	6173.9 / 5905.5	16.0 / 15.3
15	384.94	6454.5 / 6173.9	16.8 / 16.0
20	384.94	6735.1 / 6442.3	17.5 / 16.7
25	384.94	7015.8 / 6710.8	18.2 / 17.4
30	384.94	7296.4 / 6979.2	19.0 / 18.1
35	384.94	7577.0 / 7247.6	19.7 / 18.8
40	384.94	7857.6 / 7516.0	20.4 / 19.5
45	384.94	8138.3 / 7784.5	21.1 / 20.2
50	384.94	8418.9 / 8052.9	21.9 / 20.9

Table 5, RK Waste Varying Excess Air Requirements

Table 4 showed how the varying heat release rates (in BTUs/hr) effected the air flows with the same excess air requirements, same fuel flows and same air to fuel ratios. Table 5 showed the additional affect on the air to fuel ratio when the fuel contents were varied.

Adjustments to the amount of combustion air will affect the amount of CO2, CO, and O2 in the system. Analyzers are used at CIF to detect the amount of these compounds in the gas streams. Increased combustion air flow will have a resultant increase in the levels of the compounds as detected by the analyzers. Permit limits are established for the amounts of these compounds.

NOTE	The incinerator at CIF is designed to be operated with a ratio of 50% to 100% excess air. Based on Pre-Trail Burn observations, ratios were maintained in the range of 14 to 20%. Plans are in progress to allow operators to enter heating values of fuels into the DCS and having the controls preprogrammed to adjust excess air automatically.

Byproducts of Combustion

1.11	**IDENTIFY** the by-products of complete combustion.

Carbon and hydrogen are the two dominant byproducts of combustion. An important goal in incineration is to have complete combustion, with essentially no production of unburned carbon, carbon monoxide, or hydrogen. This goal applies during normal operation and when fuel supplies have been shut off and the incinerator is cooling.

Table 6, *Combustion Equations*, shows how the elements are produced and in what proportions with regard to the types of combustibles as well as the heat released (High Heating Values (HHV)) of each.

COMBUSTIBLE	REACTION	HHV (BTU/LB)
Carbon	$C + O_2 > CO_2$	14,100
Hydrogen	$H + 0.5\ O_2 > H_2O$	61,000
Sulfur	$S + O_2 > SO_2$	4,000
Hydrogen sulfide	$H_2S + 1.5\ O_2 > SO_2 + H_2O$	7,100
Methane	$CH_4 + 2O_2 > CO_2 + 2H_2O$	23,900
Ethane	$C_2H_6 + 3.5\ O_2 > 2\ CO_2 + 3\ H_2O$	22,300
Propane	$C_3H_8 + 5\ O_2 > 3\ CO_2 + 4\ H_2O$	21,500
Butane	$C_4H_{10} + 6.5\ O_2 > 4\ CO_2 + 5\ H_2O$	21,300
Pentane	$C_5H_{12} + 8\ O_2 > 5\ CO_2 + 6\ H_2O$	22,000

Table 6, Combustion Equations

Combustion produces heat and is self-sustaining as long as there is a ready supply of fuel and air available. The initial heating vaporizes and decomposes the liquid and solid fuels. The hydrogen and carbon burn to produce water, carbon monoxide, and carbon dioxide gas. The carbon monoxide mixes with air and produces carbon dioxide.

It takes time to decompose and burn fuels. The combustion reaction takes place on the exposed surface of the fuel, so the outer layer has to burn away to expose the inner portion for combustion. This can take a prolonged period of time and is similar to what happens with a charcoal grill.

Complete combustion takes place in the gas phase. It takes time for the combustible gases produced by the initial decomposition and partial burning of the fuel to mix with fresh oxygen and during that time, vessel temperature must remain high enough to burn the combustible gases.

Incomplete Combustion

1.12	**IDENTIFY** the by-products of incomplete combustion.

Incomplete combustion results in the release of carbon monoxide, smoke, unburned hydrogen, and other complex organic compounds to the atmosphere in addition to carbon dioxide and water (byproducts of complete combustion). Poor combustion can lead to partial oxidation of carbon to carbon monoxide and the nitrogen present in the organics can combine with CO to form nitrous oxides (NO_x). Some products of incomplete combustion can cause significant air pollution (unburned carbon that shows up as smoke and soot). If chlorine is present in the offgas, it creates the potential for the formation of dioxins and furans which are extremely hazardous to humans. The operating permit for an operating incineration facility imposes limits on the amount of products of incomplete combustion released.

Unburned hydrogen and carbon monoxide are combustible gases which need to be burned in a controlled manner. If hydrogen and carbon monoxide are mixed with air at a high temperature or if an ignition source is present, burning or an explosion could result.

Incomplete combustion is caused by some combination of insufficient air, inadequate mixing of fuel and air, and insufficient temperature. That is, by inadequate quantities or mixtures of oxygen, time, temperature, and turbulence.

Time

1.13	**EXPLAIN** why time is a consideration involved with the combustion process.

Retention, or residence, time is used for solids and gases in different contexts in the combustion process. The residence time of gas in the Secondary Combustion Chamber is the time from the point at which all wastes and secondary combustion air have been injected into the chamber to the exit point from the chamber or combustion zone. The SCC is sized to have a minimum of two seconds gas residence time above the SCC burners at a temperature of 2012 °F. Residence time may be adjusted by excess gas flow created by the action of the induced draft and controllers (dampers, valves, etc.). The fan capacity and controls of the system should limit the gas flow so that minimum required residence time is maintained.

In a rotary kiln (RK), residence time of the fuels and wastes in the region of high temperature is also controlled by the rotational speed. If kiln rotational speed were too fast, this could lead to the incomplete combustion of hydrocarbon fuels (solids).

Turbulence

1.14	**DESCRIBE** the methods used to promote turbulence in the combustion process.

Turbulence is an indication of the degree of mixing occurring in the combustion chambers. Turbulence is a desirable requirement for combustion to ensure adequate agitation and mixing of the fuels, combustion air and gases. When determining the degree of mixing, or turbulence occurring in the chamber, consideration must be given to the diameter of the chamber, gas velocity, the gas viscosity, and the gas density. Turbulence is achieved by various means, including the following:

- Liquid fuel is atomized into small droplets by atomizing steam and mixed with air by the burners. The burners cause swirling of the air and fuel to promote mixing. Dirt or ash can clog the atomizer and disrupt the spray, thus causing inadequate mixing and incomplete combustion. Heating of the burner tip can cause premature decomposition of the fuel, leading to formation of solid carbon ("coke") which clogs the burner tip. Low fuel pressure or low atomizing steam pressure can cause inadequate atomization, this will lead to incomplete combustion.
- Blowing excess air into the kiln when burning solid waste causes swirling due to mechanical and thermal effects, and mixes with the solid fuel and combustible gases (carbon monoxide and hydrogen) in the kiln.
- The gas exiting the kiln makes a more than 90 degree turn going into the SCC, which promotes mixing.
- The SCC is a vertical cylinder with two burners mounted off-center firing horizontally near the lower part of the chamber. The center mounting of the burners promotes swirling and mixing of the gases in the SCC. The burners maintain high temperatures in the chamber, as well as promoting mixing

Temperature

Heat loss from the combustion system is limited by the refractory walls. An open fire, such as a camp fire, loses a great deal of heat by radiation to the outside, so the combustion products cool very quickly. For this reason as well as the uncontrolled flow of a great deal of excess air, open fires produce large amounts of carbon monoxide and smoke. In the CIF, the refractory lining limits heat loss throughout the combustion zone in order to enable complete combustion.

Temperatures in the combustion process can be controlled by varying the excess combustion air flow. Figure 11, *Combustion Gas Temperature vs. Excess Air*, shows the relationship between gas temperature and excess air variations.

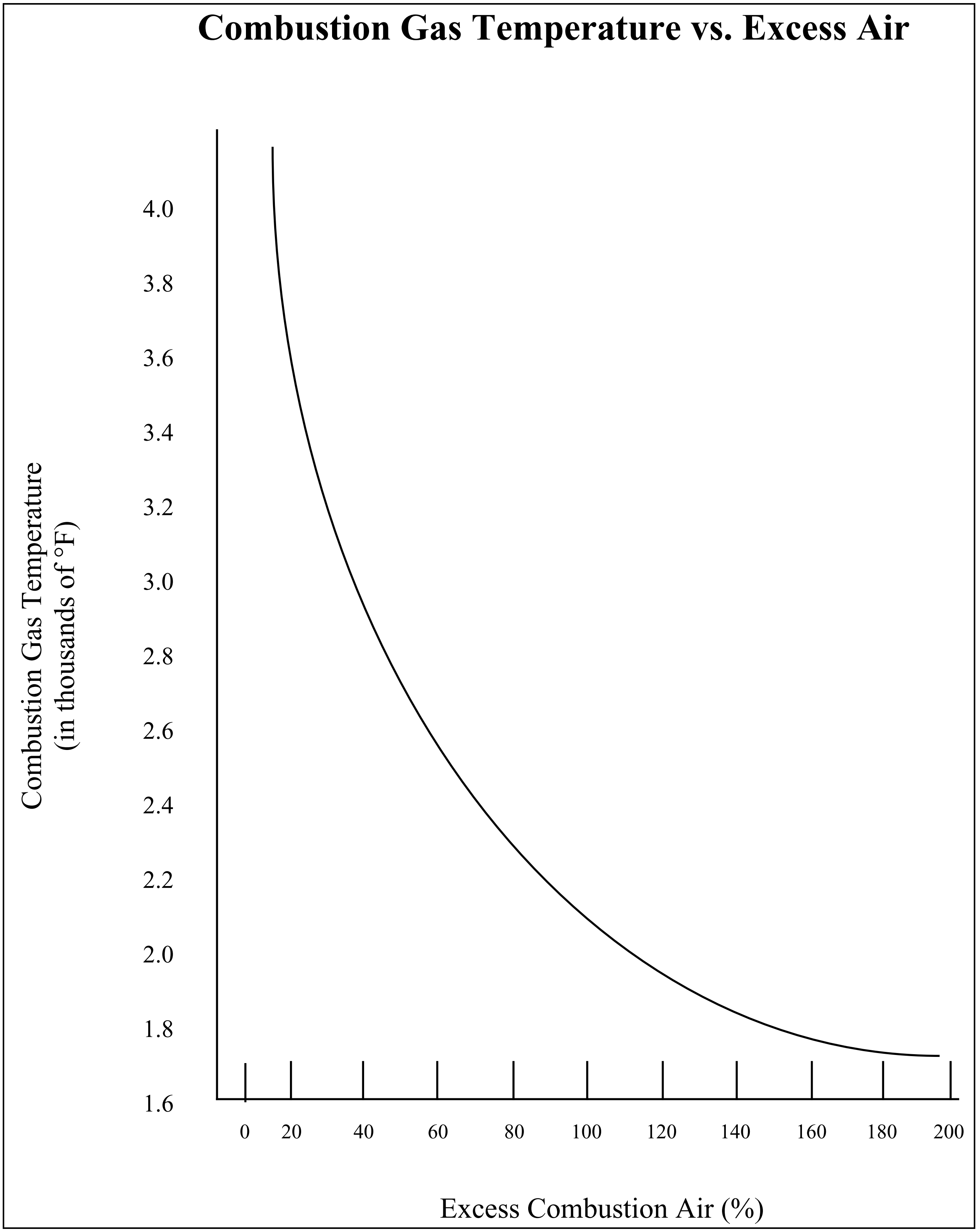


Figure 11, Combustion Gas Temperature vs. Excess Air

The figure shows that for a given material (methane is used in the example), increasing the amount of excess combustion air will have the effect of lowering the temperature of the combustion gases. Empirical evidence at CIF has shown this to be true. Operating in the range of 50 to 100% excess air (design values) has hindered reaching nominal operating temperatures throughout the kiln. Consideration must be given to the fact that using excess air to cool combustion temperatures will have the effect of increasing the mass and volume of combustion gases thus increasing the sizing requirements for the fans and blowers as well as the rate of waste feed.

Potential Problems

1.15	**DESCRIBE** the potential problems associated with combustion to include causes, effects and methods of prevention for the following: a. Excessive temperature b. Seal failure c. Pressure excursions d. Waste feed fires

Excessive Temperature

Overfiring or burning of excessive amounts of fuels and wastes can cause high temperatures. Failure of controls and safeguards may lead to high temperature conditions. Excessive temperatures can damage the refractories by disforming, expanding and cracking. Excessive temperatures also cause formation of slag on the kiln walls or elsewhere in the system. Slag is ash material such as metal, glass, sand, etc., that is so hot it begins to melt. Slag clings to surfaces and builds up which could disrupt or block flow patterns, interfere with proper combustion, and dam up solids in the kiln. Slag reacts chemically and mechanically with refractories causing damaging. Keeping ash and residue too long in the kiln can promote slag build up. A low kiln rotational speed could affect the residence time.

Firing rates are limited by system design capability and by procedures in order to prevent excessive temperatures, and to prevent excessive gas velocities. "Tertiary air" can be blown into the bottom of the SCC to limit temperature if necessary.

Seal Failure

Seals can fail due to thermal breakdown, incorrect material selection or design, or chemical corrosion from reaction with fuels or wastes. Failure of seals can allow air to leak into the kiln in an uncontrolled manner, cooling the gas locally and quenching combustion. Failure of the seals could also result in releasing combustion gases, wastes and fuels or contaminants into the atmosphere. Seals that can fail include the kiln rotary seals, the water seal in the ash tank, and the door and gate seals on the ram feed system.

Seal failure can be prevented by correct selection and installation, proper warmup and cooldown of the incinerator, boiler or heat exchanger, and routine inspection. Inspection should focus on both the physical seal and the surrounding area to ensure no evidence exists if fuel leaks or deterioration.

Pressure Excursions

Instabilities in combustion for any reason can cause pressure excursions. Pressure inside the combustion system is normally slightly below atmospheric so small leakage is to the inside. A pressure excursion can cause leakage of gases, fuels, contaminants and ash out of the vessel. Instabilities can be caused by burner or control system malfunction or by changes in solid waste combustion. Changes in solid waste combustion can occur because of variations in moisture content, volatility or introduction of combustible liquid or gas. Pressure excursions can also be caused by malfunction of forced draft or induced draft fans or their dampers.

Minute pressure changes (burps) cannot always be avoided. Personnel need to ensure that vessel pressure controls and safeguards are continually in operation and monitored to prevent large and potentially damaging pressure excursions. Operators should also pay attention to the characteristics of wastes and fuels to ensure that their contents are suitable for combustion in the system.

NOTE	To avoid pressure excursions, air flow should be at minimum during burner start ups. Numerous RK HI HI Pressure trips occur when the SCC Fuel Oil burner was started with the combustion air flow controls set at high/maximum values.

Waste Feed Fires

Wastes can ignite prematurely in the feed system from the radiant heat generated by combustion or from back flow of hot gas from the kiln into feed housings. Fire in support systems or the incinerator cause system shutdowns and process interruptions. Fires could cause personnel injury, release to the environment or equipment damage.

Ignition by radiant heat is normally prevented by the refractory lined air-lock door at the ram discharge into the kiln. The door inhibits flow of hot gas into the ram housing. An air supply and exhaust system for the housing is intended to supply the housing with purge air while the door is open, then evacuate leakage gas while the door is shut. The ram, door, air supply and exhaust controls are interlocked to achieve proper sequencing and prevent combustion in the housing (if the controls are in the AUTO mode of operation). Malfunction of these controls could lead to a fire in the housing. Nitrogen snuffing gas is supplied from six nitrogen storage bottles to extinguish such a fire.

NOTE	The waste feed fire incident in the BGI is a good example of why waste feed fires are a cause of concern. A fire in a housing caused a Halon release to extinguish the fire. But, because of the high temperatures involved, phosgene gas was formed causing a personnel hazard.

Review

1) Identify four chemicals or compounds that are constituents of air.

2) Sulfur is present in most organic fuels. Why is the presence of sulfur a cause for concern?

3) What is atomization? Where does atomization occur in the combustion process? Why is atomization required?

4) What are the two dominant byproducts of complete combustion? Where does complete combustion occur in the process?

5) What are three of the byproducts of incomplete combustion? Why is incomplete combustion a cause for concern? What are three possible causes of incomplete combustion?

6) Identify the three T's of combustion and give examples of how they are controlled in the facility.

7) What are four of the possible problems associated with the combustion process? Give an example of the effect of each type of problem.

CIF COMBUSTION AND HEAT TRANSFER

Introduction

Combustion and heat transfer principles are applied throughout the CIF, not only in the incineration process, but in the variety of heat exchangers located in the area. Some areas have designed features to prevent combustion or heat transfer (nitrogen blanketing of the waste storage tanks to prevent exothermic reactions).

Incinerator

1.16	**DESCRIBE** starting the combustion process in the incinerator to address the following aspects: a. Purge b. Waste feed initiation c. Combustion control d. Temperature control e. Burner Management System

The incinerator uses controlled combustion to thermally reduce the volume of non-radioactive hazardous waste (NRHW) and low-level radioactive waste (LLRW). The process is initiated any time a sufficient volume of waste is stored or delivered. Prior to initiation of flame in the RK, the system is purged of any remaining combustion gases or fuels by operation of the Solids Combustion Air Fan. This is done to prevent explosion or fire from the ignition of uncontrolled vapors or fuel. After 6.5 minutes, the purge is complete. Operators should monitor the combustion air during and after purge to see the differences in pressure indications as evidence of a successful purge. If the purge is not successfully completed, a re-purge interlock will safeguard the incinerator from premature ignition of the burners.

NOTE	The Solids Combustion Air Fan is used for the purge of the incinerator at CIF. The damper on the outlet of the fan is adjusted for a flow rate of 30, 000 acfm for purge. When purge is complete, the damper is manually adjusted to 5,000 acfm for burner ignition.

After the purge is complete, propane is then used to start a fuel oil burner. Fuel oil flow is regulated by a low flow control valve until a steady flame is established (indicated by redundant flame scanners). The incinerator is gradually heated up using the fuel oil until it reaches temperatures high enough to begin incineration and evaporation of liquid and solid wastes.

Initiation of liquid and solid waste feed requires sufficient temperatures (RK temperature between 1420°F and 1620°F), adequate supply pressures of fuel, air, atomizing steam, proper RK pressure, and interlock permissives for primary and auxiliary systems (setpoints to be fully addressed in the incinerator module). To ensure proper combustion of the wastes, instruments and controls will modulate fuel and air flows based primarily upon the outlet temperatures of the RK and the SCC.

Temperature transients in both the RK and SCC out of or near operating limits cause adjustments of fuel, air and waste feed flows. The order of the adjustments is fuel, solid waste, liquid waste, and combustion and forced draft air. Adjustment priorities are based upon the BTU content and associated heating values of the fuel and wastes. These values will be discussed in detail in the incineration module and incineration overview.

The combustion of the materials in the incinerator is safeguarded by the Burner Management System (BMS) in conjunction with the Distributed Control System (DCS). The BMS provides interlocking for the burners, fans, control valves and instruments of the incinerator to allow safe and efficient operation of the process. The initial purge of the system is an example of a safeguard feature of the BMS. The fuel control valves and safety shut-off valves (SSOVs) supplying fuel and waste to the RK and SCC burners will not operate until the purge has been completed. This prevents admitting fuel into an incinerator that may already contain an unsafe level of combustible gases. If operating personnel were to attempt to ignite the fuel oil while the combustible gases were still present, the combustion reaction could become an explosive reaction.

Offgas System

1.17	**DESCRIBE** the heat transfer process in the following Offgas System Components: a. Quench vessel b. Reheater

The Offgas System is designed to remove any particulate or contamination from the exit gases of the incinerator to allow clean and environmentally sound emissions from the stack. The system quenches, scrubs, separates, adjusts and filters the exit gases before routing them to the atmosphere. While there is no combustion going on in the system, there is a significant amount of heat transfer occurring. Heat transfer in the quench occurs when the gas stream is sprayed and cooled and the volume of the gas stream significantly reduced. Heat transfer occurs in the reheater when the stream passes across coils that are supplied with 180 psig steam. This is done to remove any residual moisture and prevent damage to the HEPA filters downstream

Exothermic Reactions in the Tank Farm

1.18	**EXPLAIN** the concerns regarding exothermic reactions in the storage tanks at the Tank Farm to include: a. Definition of an exothermic reaction b. Method of prevention c. Possible consequences of occurrence

While no combustion is designed to occur in the Tank Farm, the potential for uncontrolled combustion exists. These combustion reactions are referred to as exothermic reactions. An exothermic reaction involves a significant release of heat as a result of mixing volatile, incompatible or reactive chemicals. If an exothermic reaction occurred, tank structural failure or explosions could result. To prevent or minimize the potential for exothermic reactions, a nitrogen blanket is provided on each of the liquid waste tanks. The blanket displaces any oxygen that may exist thereby removing a leg of the fire triangle.

HVAC

Heat transfer is performed by the building air handling system. The system takes atmospheric air and delivers it through ductwork to the areas of the facility that need conditioned air. The system is equipped with both chilled water coils for cooling and preheat coils for heating. The Box Handling Area is also provided with steam operated space heaters for temperature control.

The ventilation equipment associated with the HVAC System is also used to ensure that the high temperature and potentially contaminated gases and combustion air streams are maintained inside enclosures and vessels. Ventilation is arranged so that any high temperature or contaminated gases will flow to the areas maintained at the lowest pressures. Forced circulation provides a flow path from the Box Handling Area to the Solid Waste Feed Area to the Ashcrete Area. The ventilation system is a good example of convection heat transfer.

Facility Operations

1.19	**DESCRIBE** the reasons heatup and cooldown rates are controlled and the methods of control.

Two of the operations associated with the incinerator combustion process are heatup and cool down. The rates of both processes must be controlled to prevent thermal stress. A discussion of each follows.

Heatup

In a heatup situation, the inner wall of the RK or SCC is heating up faster than the outer wall, which applies stress from the outer wall to the inner wall in an attempt to keep it from expanding. This is known as a tensile stress due to the inner wall expanding faster than the outer wall. Heatup rates are set to allow for the even heating of the components which also allows the stresses to be alleviated in a controlled manner. Burner controls and the DCS are used to adjust and program safe heatup rates.

Cooldown

Cooldown of the system will cause the inner wall of the RK or SCC to cool faster than the outer wall cools. This causes the inner wall to contract faster than the outer wall, which causes compressive stress to be applied by the outer wall to the inner wall. Cooldown rates are set to limit the compressive stress applied due to uneven cooling of components and to allow sufficient time for the stresses to be alleviated. Always follow established procedural cooldown rates to minimized the applied stress.

Review

1) Why is a purge performed prior to start up of the incinerator? How is the purge performed?

2) Identify two locations in the Offgas System where heat transfer occurs?

3) What is an exothermic reaction and how is it prevented in the liquid waste storage tanks in the Tank Farm?

4) Identify and differentiate between the two types of stress applied to the incinerator during heat up and cooldown.